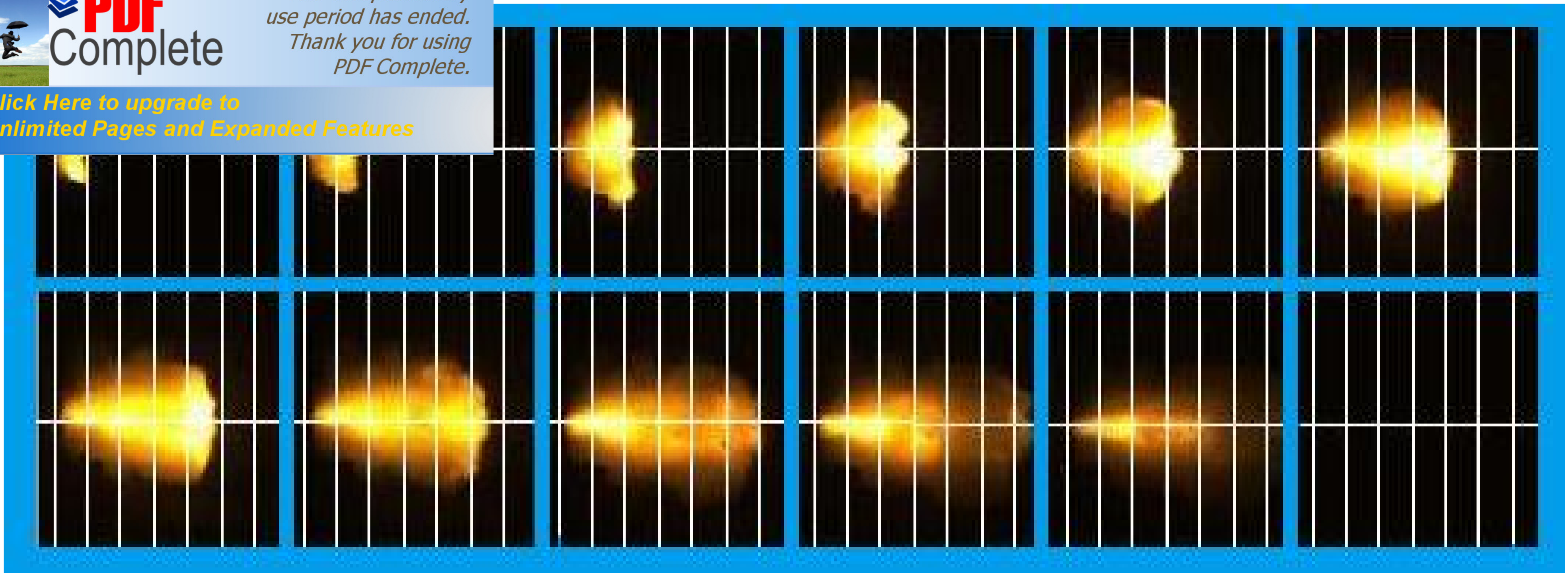

Consideration of the Ignition Delay of Gun Propellants

M. J. Taylor, C. R. Woodley, S. R. Fuller, S. Gilbert, J. I. Gransden

A presentation to: 24th International Symposium on Ballistics, New Orleans, Louisiana September 22-26, 2008

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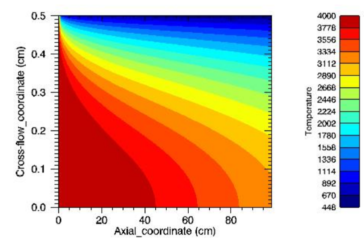
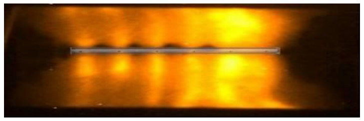
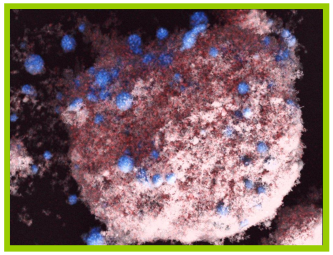
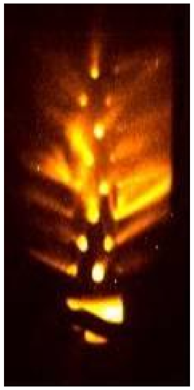
04 Analytical Treatment of Ignition Delay

05 Conclusions









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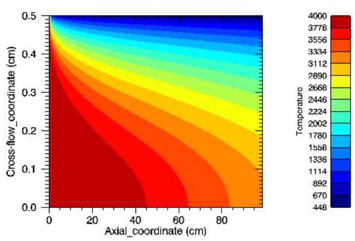
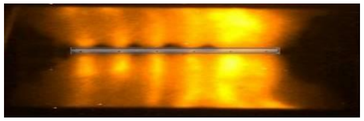
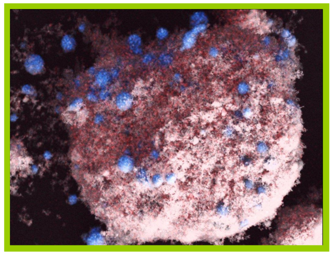
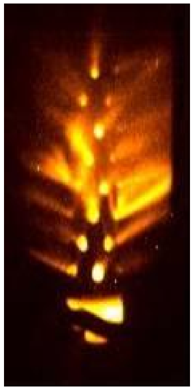
01 Background









Full compliance with insensitive munition (IM) requirements

Increased muzzle energy

Future propellant charges being more difficult to ignite

Existing ignition systems are likely to prove inadequate

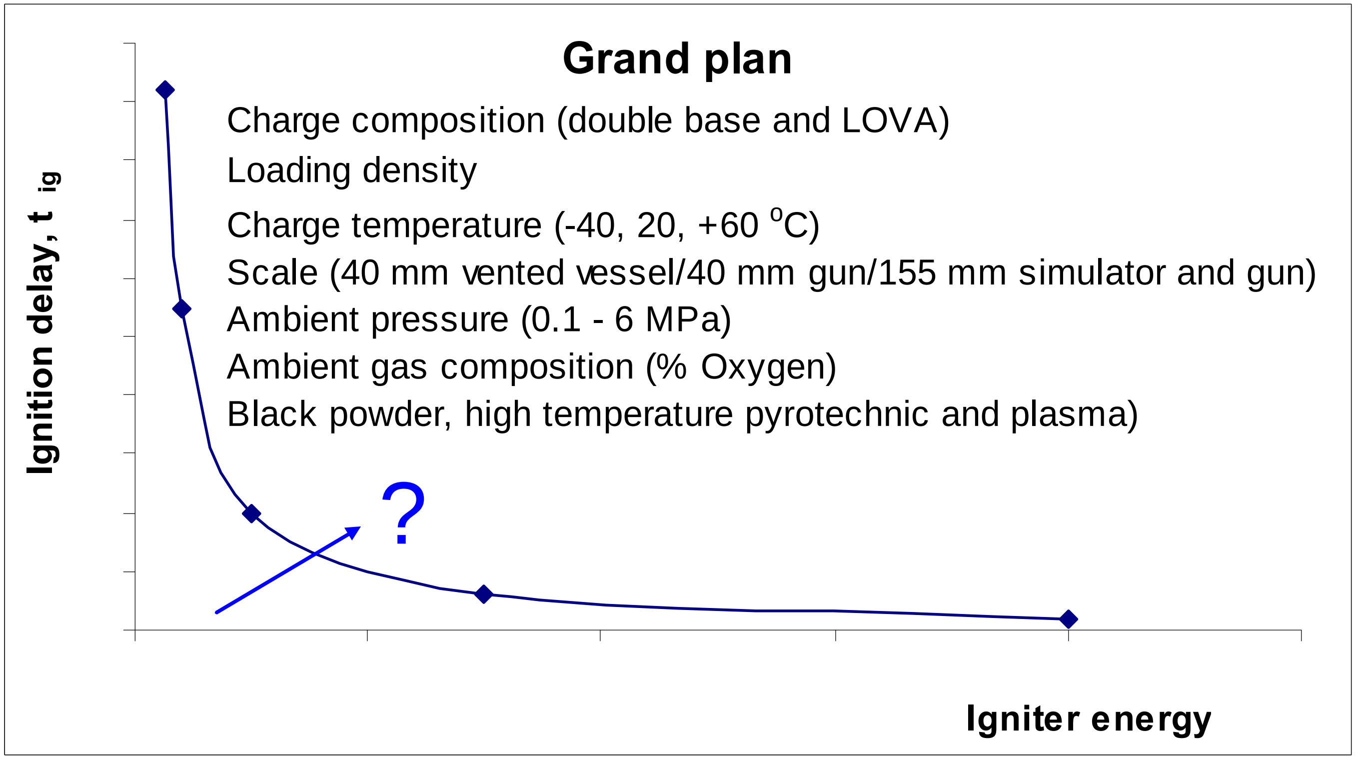
Significant effort to increase the understanding of ignition phenomena

Enabler

A MOD DTIC programme designed to address this need

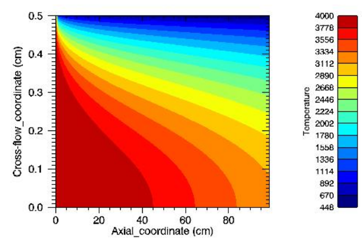
Includes the UK component of the EUROPA Ignition Phenomena TA between French, German, Swedish and the UK Govnt's

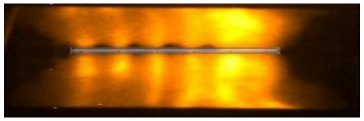
Aimed at increasing the depth of understanding of ignition by experiment and encapsulate in computer modelling

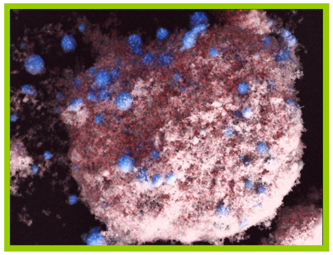


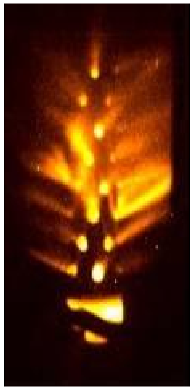
- Ignition delay is an important and sensitive measurand
  - Over-ignition leads to pressure waves: **modelled with reasonable confidence**
  - Under-ignition leads to long ignition delays: **cannot be predictively modelled**

02
Empirical Expression for Ignition Delay









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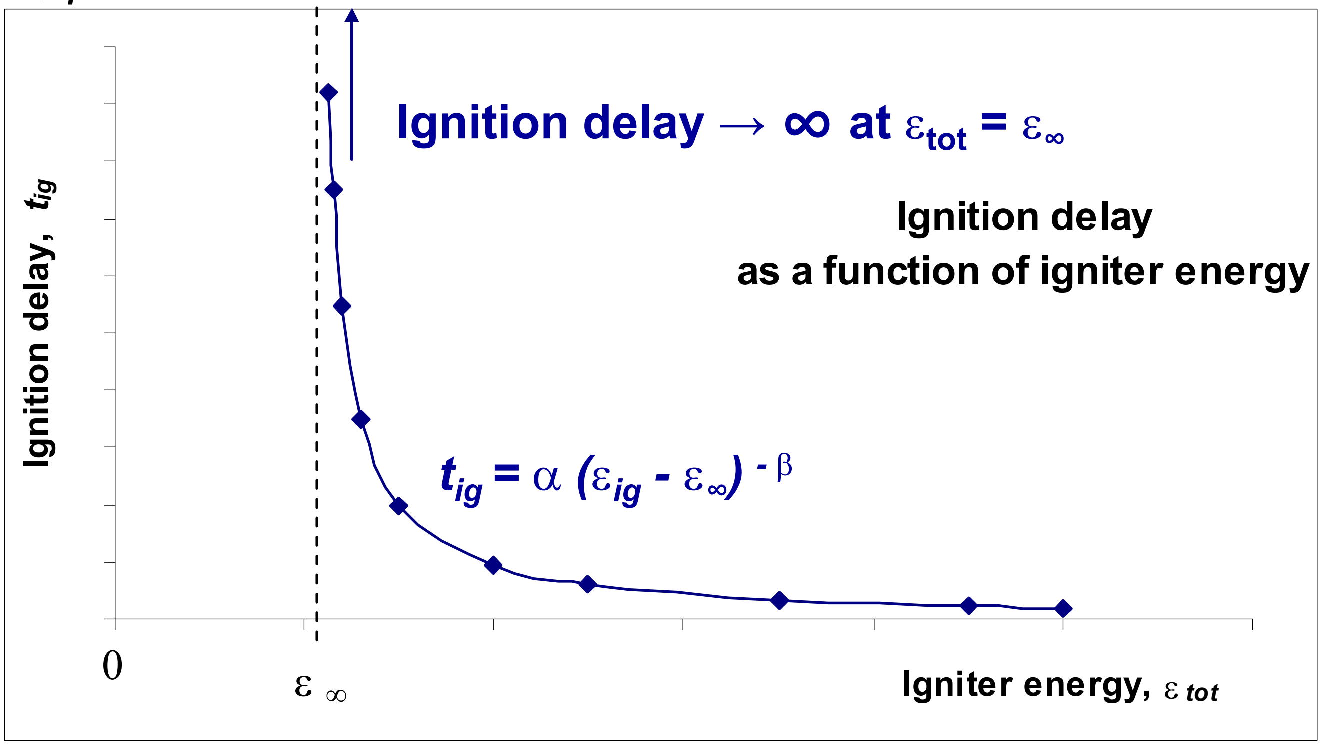
ession for Ignition Delay

$$t_{ig} = \alpha\ (\varepsilon_{ig} - \varepsilon_{\infty})^{-\beta} \qquad (1)$$

where ε_{∞} is the energy leading to mis-fire ($t_{ig} = \infty$ when $\varepsilon_{ig} - \varepsilon_{\infty} = 0$);

α, β are constants



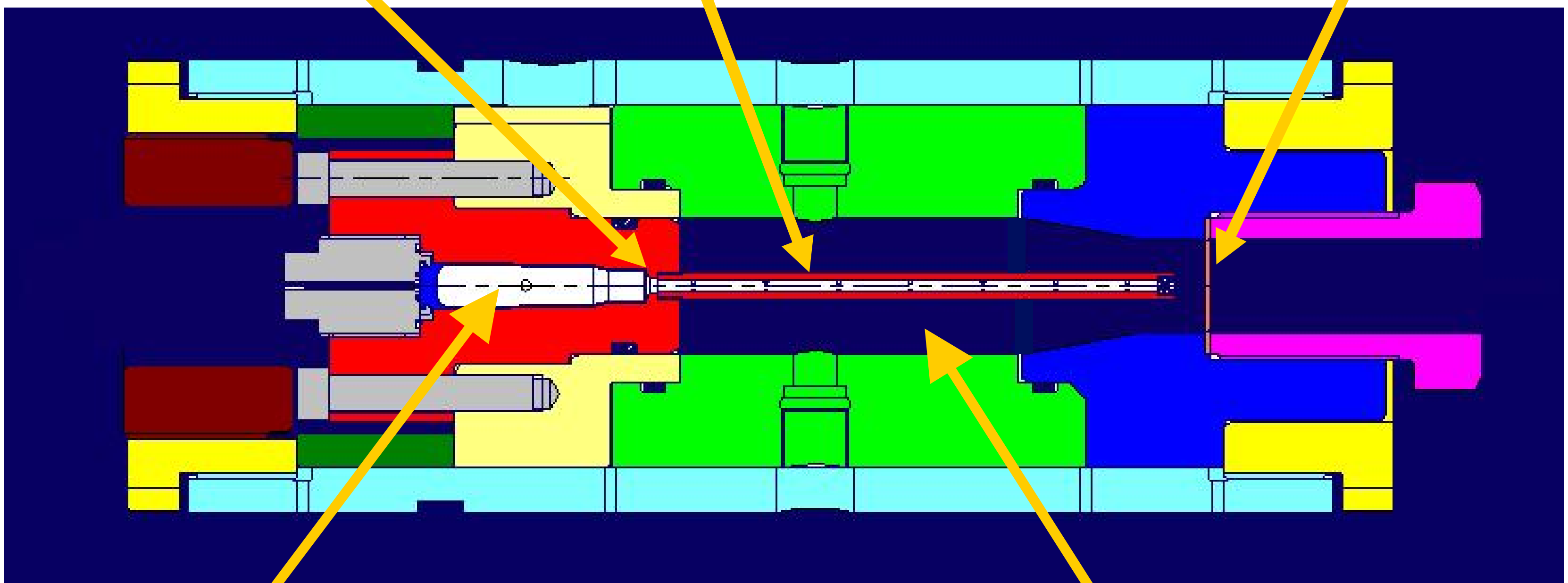
Aims:

Determine function coefficients for propellant ignition for a range of parameters

Use data for ignition model validation and model development

ession for Ignition Delay

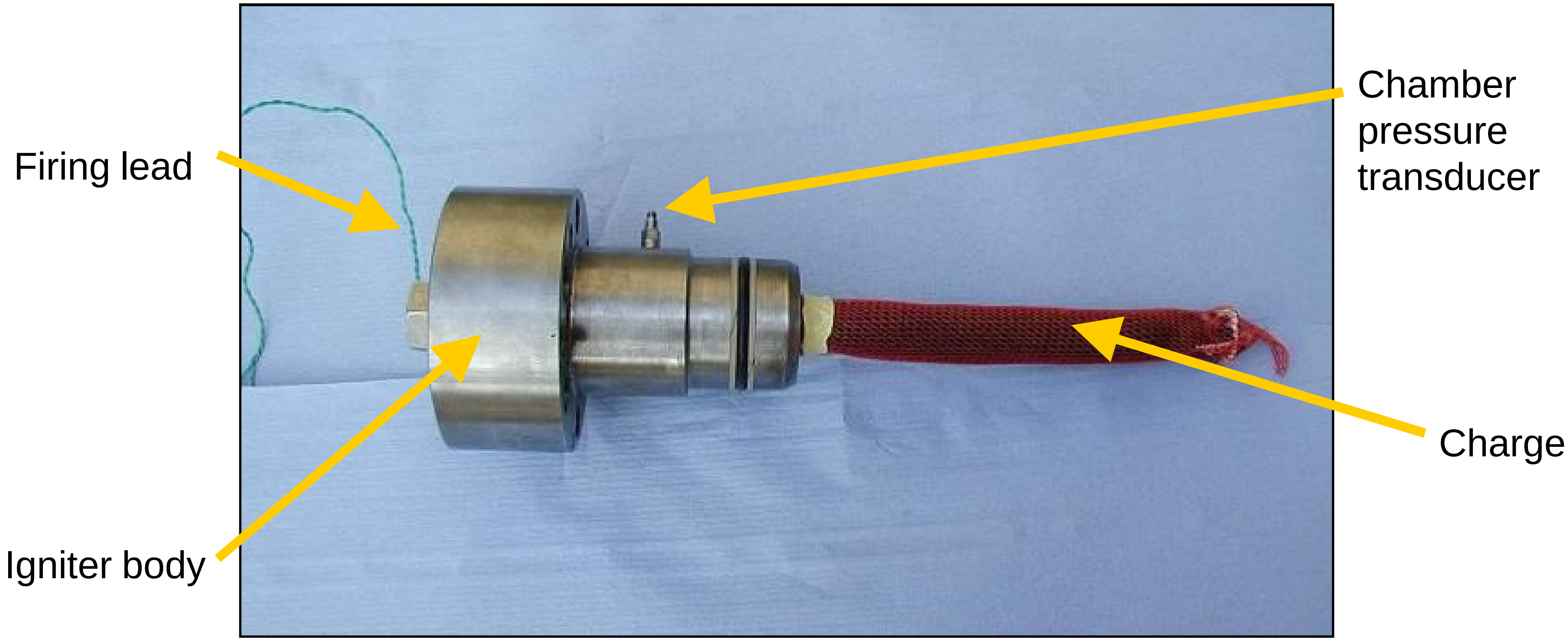
Instrumented 40 mm black powder igniter and vessel



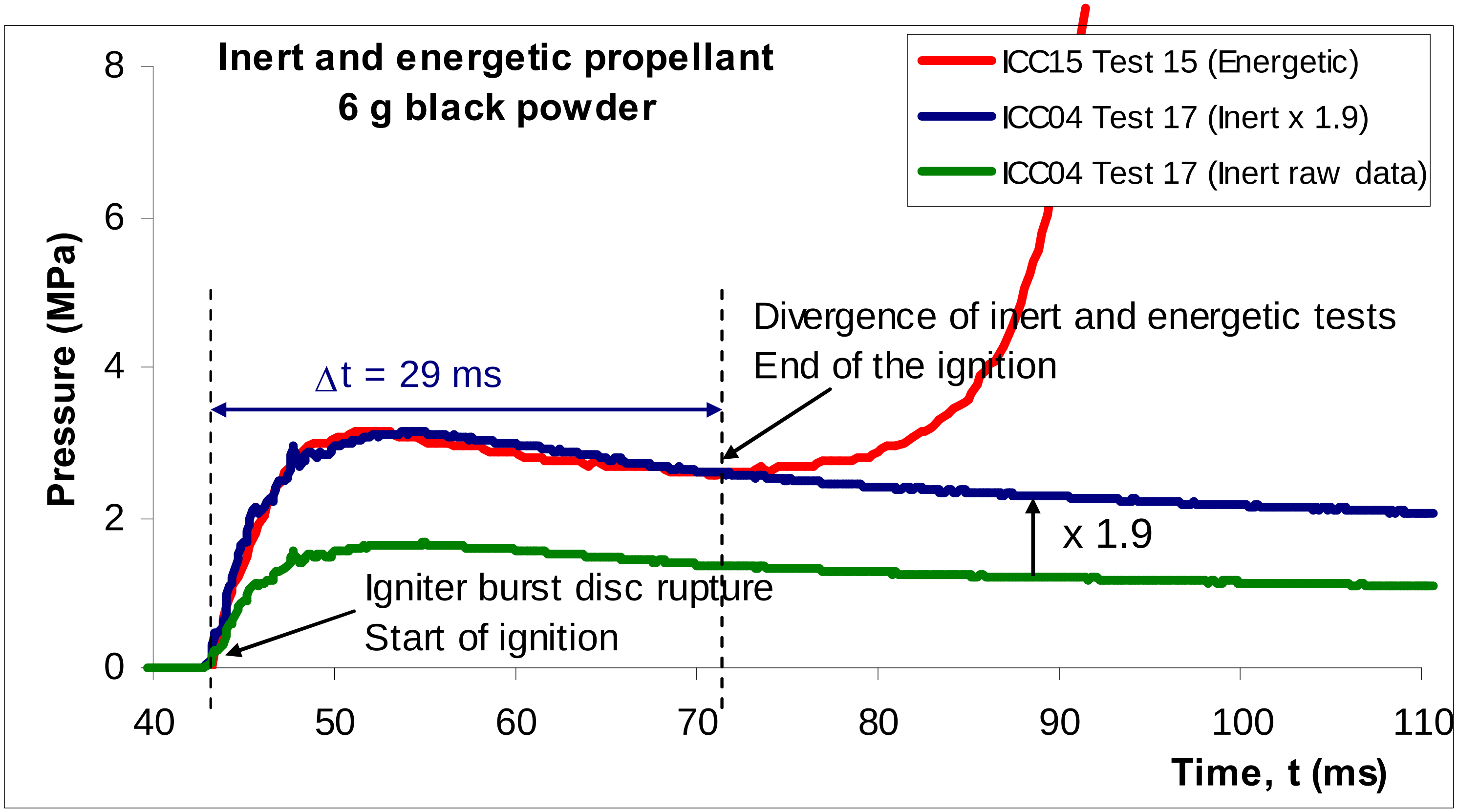
ession for Ignition Delay

The propellant charge is made around the piccolo tube

Loading density is adjusted by radial (as opposed to longitudinal) adjustment

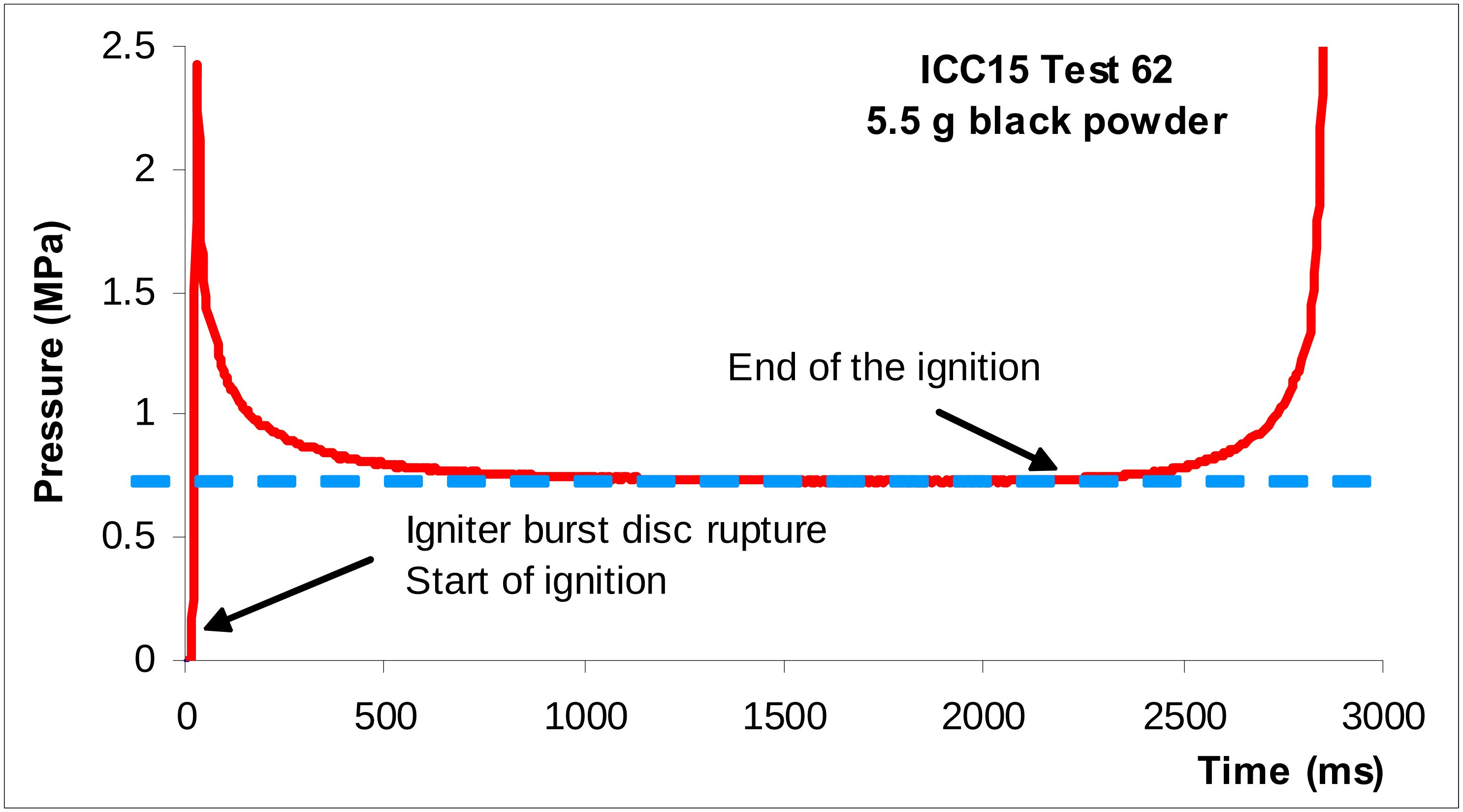


ession for Ignition Delay



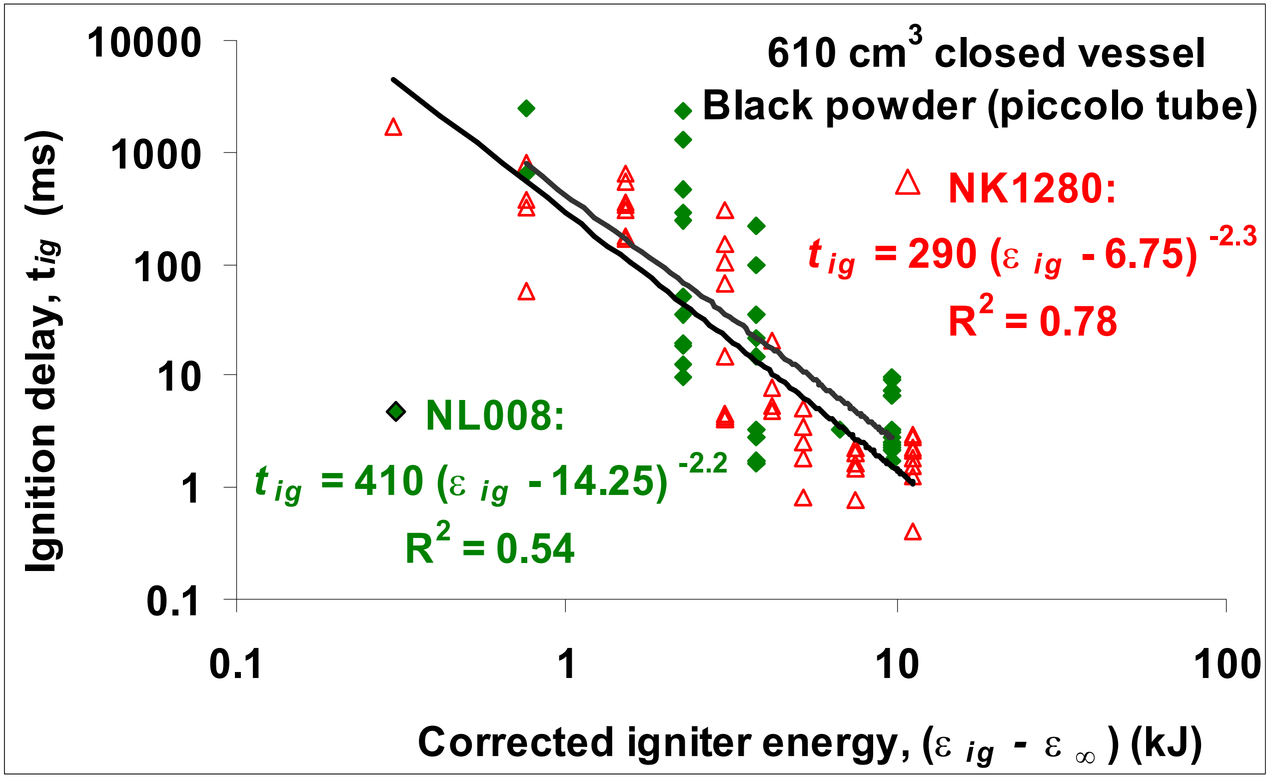
Energetic tests generated up to 4 times more pressure than inert tests

ession for Ignition Delay



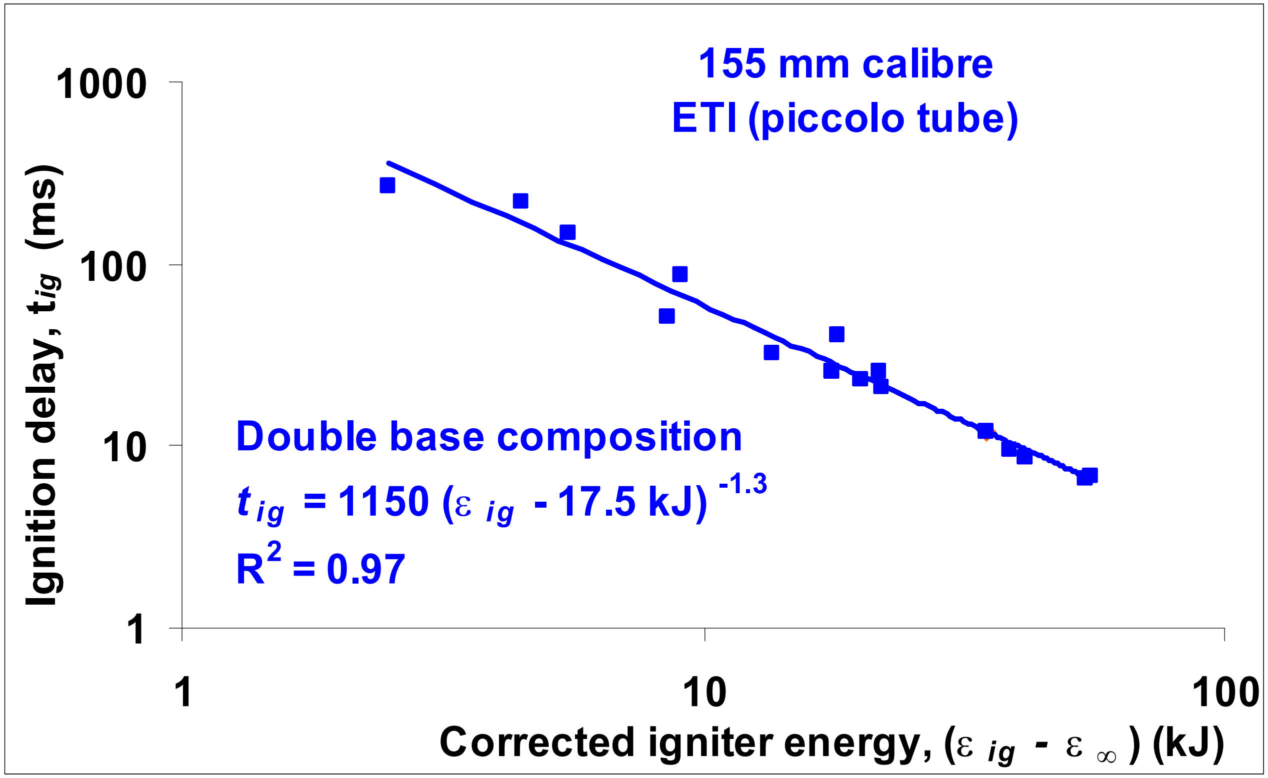
End of ignition can be defined by change in dp/dt

ession for Ignition Delay



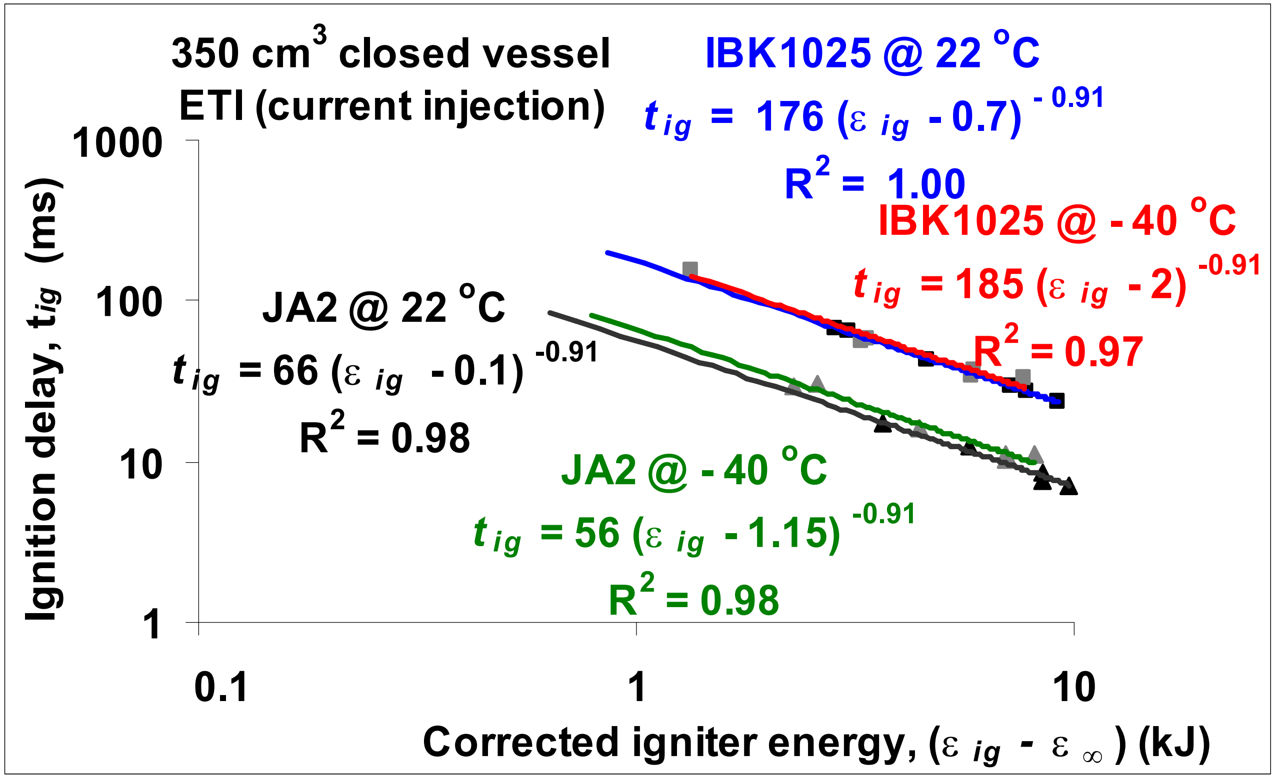
Ignition using a piccolo igniter with black powder ï poor repeatability at cannon calibre

ession for Ignition Delay



Ignition using a piccolo igniter with black powder ï good repeatability at 155 mm calibre

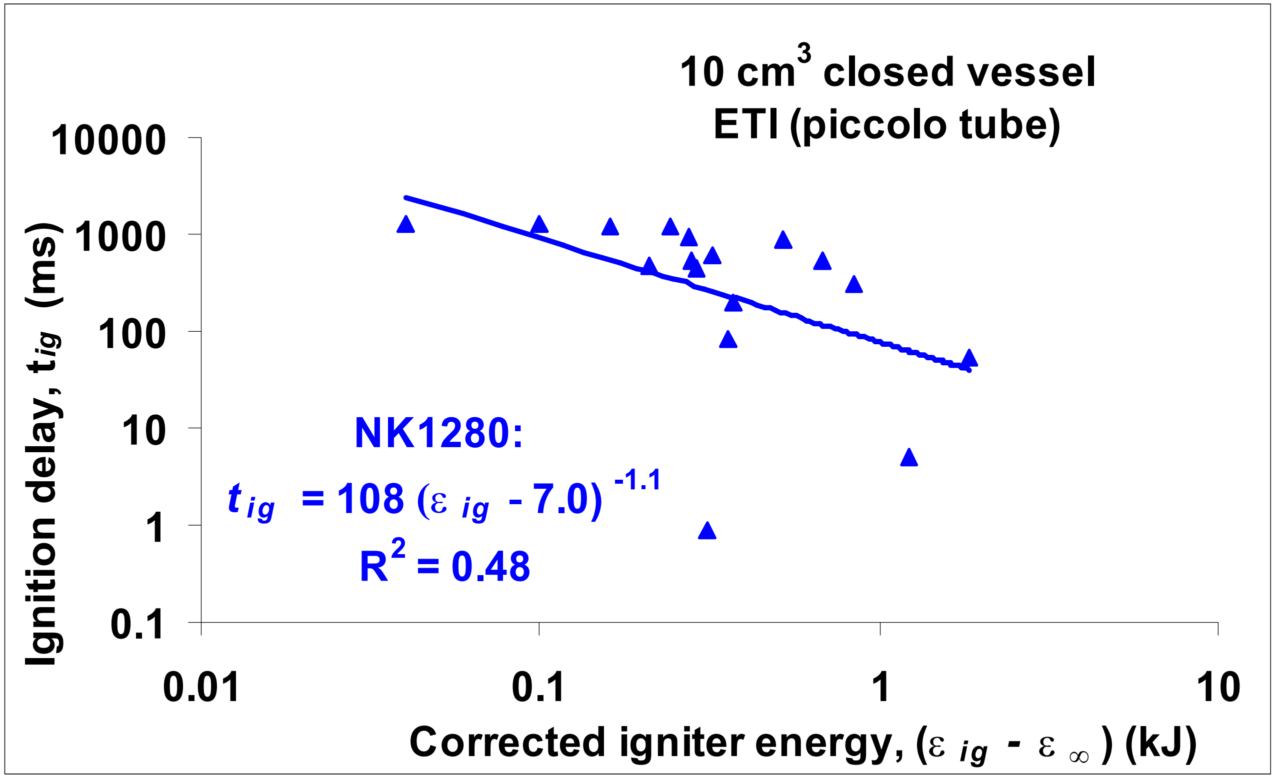
ession for Ignition Delay



Ignition using a current injection igniter with ETI ï good repeatability at cannon calibre

Results curtsey of TNO - M. Bakker, C. Schoolderman, C. van Driel and E. Folgering, ñETC Ignition of LOVA Gun Propellantsò, 37th Int. Annual Conference of ICT, Karlsruhe, Germany, 27th June - 30th June, 2006

ession for Ignition Delay



Ignition using a piccolo igniter with ETI ï poor repeatability at cannon calibre

Consistent poor repeatability at cannon calibre with piccolo igniteré .

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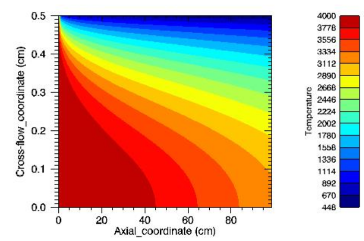
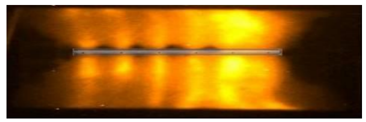
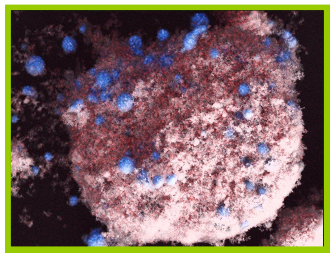
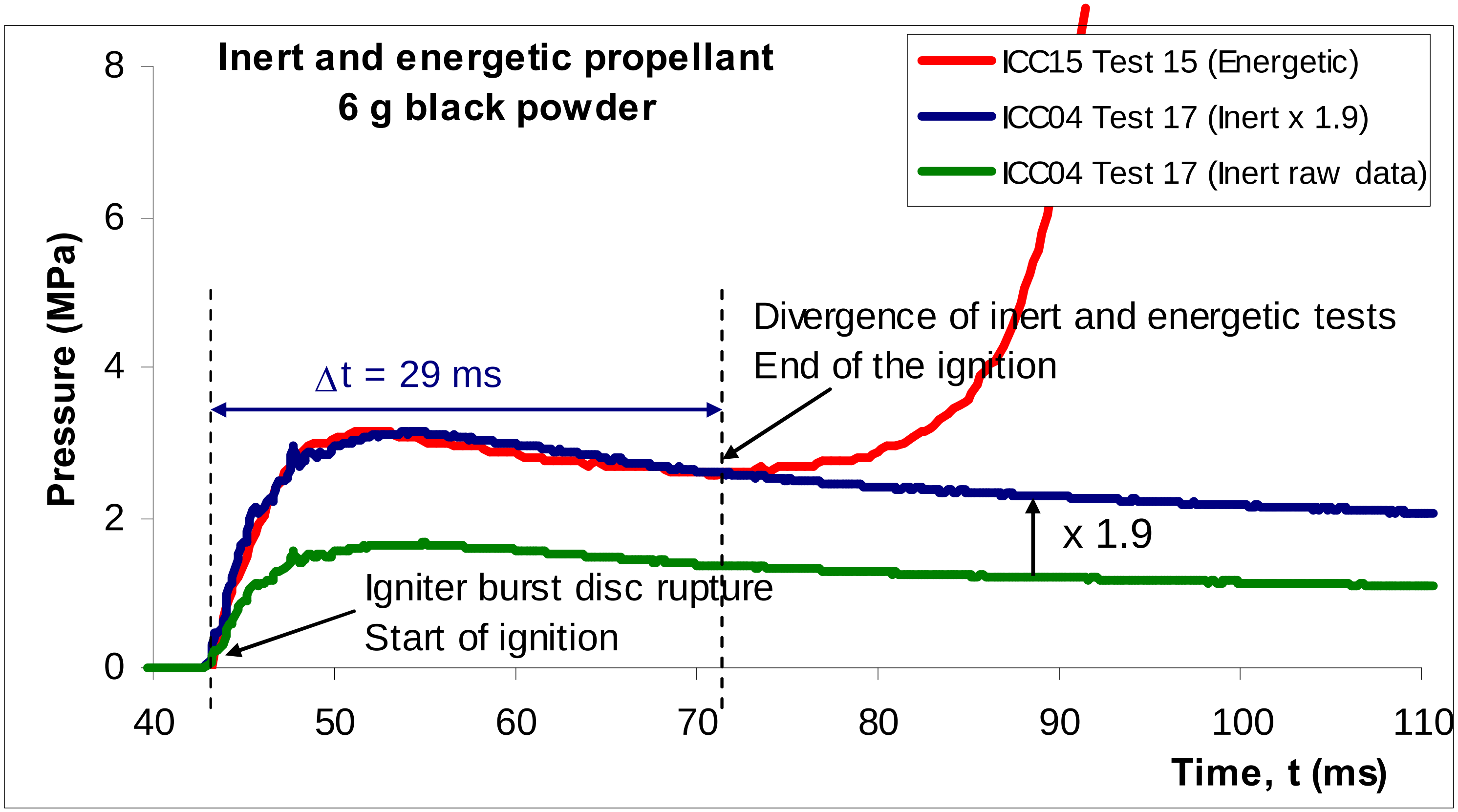
03
The Ablation Coefficient







oefficient



Energetic tests generated up to 4 times more pressure than inert tests

oefficient

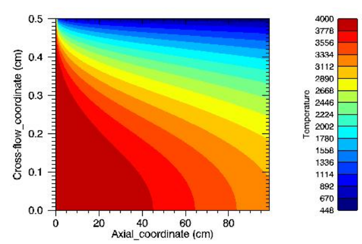
- It is proposed that erosive burning (ablation) of the propellant is caused by the discharging igniter

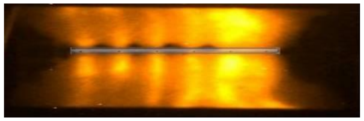
  This adds energy and pressure to the system during the ignition phase

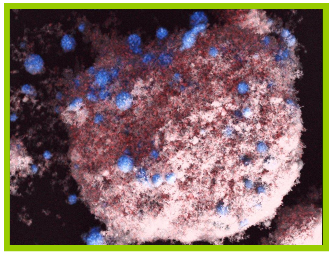
$$t_{ig} = \alpha\,(\varepsilon_{ig} + ap - \varepsilon_{\infty})^{-\beta} \qquad (2)$$

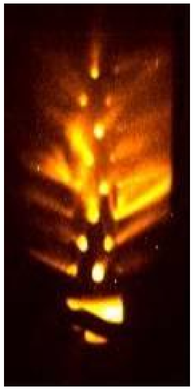
- Variability in ignition delay caused by variability in ablation coefficient, *a*
  - The factor, *a,* slightly varies from test to test
- The factor, *a,* greatly varies with test conditions
  - Cannon calibre ETI using a piccolo igniter gives the largest factor
    - Highly brisant (hard) igniter
  - Cannon calibre ETI using current injection gives the least factor
    - Low brisance (soft) igniter

04
Analytical Treatment of Ignition Delay









tment of Ignition Delay

- The time to ignition can also be described by:

$$t_{ig} \sim \tfrac{1}{4}\,\pi\;\lambda\;\rho\, c_p\, T_p^{\,2}\, I^{\,-2} + t_{stab} \qquad (2)$$

where

λ is the propellant heat conductivity

ρ is the propellant density

c_p is the propellant specific heat

T_p is the propellant pyrolysis temperature

I is the heat flux

- t_{stab} is the time required for initiation and stabilisation of gas phase reactions and is only significant during over-ignition when the heat flux is large and I $^{-2}$ diminishes (i.e. when ignition delays are small)

tment of Ignition Delay

- The expressions for ignition delay, equations (2) and (3), are obviously describing the same event but from empirical and theoretical perspectives
  - The theory considers the rate of heat transfer and the experiment considers the time-integrated energy
- However, these expressions can be equated by substituting for heat flux with time-integrated energy in equation (3)

tment of Ignition Delay

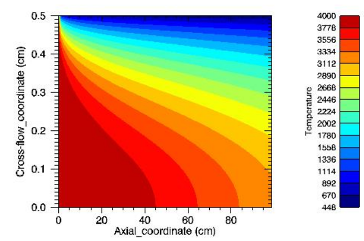
- If the rate of energy transfer is assumed to be constant then, for relatively long ignition delays:

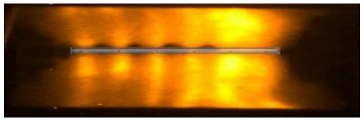
$$t_{ig} = \alpha\,(\varepsilon_{ig} + ap - \varepsilon_{\infty})^{-\beta} = \tfrac{1}{4}\,\pi\,\lambda\,\rho\,c_p\,T_p^{2}\,t^{2}\,A^{2}\,\varepsilon^{-2} \quad (4)$$

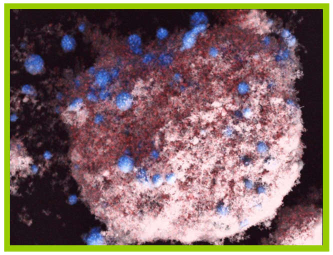
  where ε is the igniter energy transferred to the propellant, t is the time to transfer ε and A is the surface area over which ε is transferred

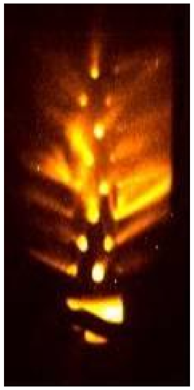
- This comparison gives a useful platform from which to understand and compare the various values of the igniter coefficients

05
Conclusions









- Studies have investigated ignition delay of gun propellant
  - An empirical treatment of the relationship between ignition delay and igniter energy agrees in form with an analytical expression
  - The correlation between experiment and theory is excellent under some conditions, but appears to be poor under others
  - An hypothesis to explain this has been put forward, that some igniter designs produce excessive ablation of propellant
- Some of the main assumptions in the theoretical treatment are invalidated, but the comparison between the experiment and theory has been surprisingly successful
- Efforts to understand the physical and chemical processes occurring during the long ignition delays are planned

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